PHOTOCELLS AND GLOW LAMPS

No. 25 FR1.

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

> An aim in life is the only fortune worth the finding; and it is not to be found in foreign lands, but in the heart itself.—ROBERT LOUIS STEVENSON.

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NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

NCP1M91731

Printed in U. S. A.

Photocells and Glow Lamps

THE PHOTOCELL

The development of the photoelectric cell has been a remarkable gift to man. Its field of application has just been scratched, and time will show many more new applications of this modern invention. This device is really an electric eye that is much more accurate than a human eye. Everyone knows that the human eye responds to various light intensities and also distinguishes color. Our electric eye does the same thing, but better. The human eye is connected to the human brain and the latter interprets what the eye sees and sometimes misinterprets what the eye really sees; the electric eye, on the other hand, does not have that failing and is strictly a true response device.

The photoelectric cell, something like a vacuum tube in appearance, is extremely sensitive to variations in light intensity and to variations in color of light. When connected in a suitable electric circuit, if light is allowed to strike the cell, a current immediately appears in the electric circuit. Furthermore, the cell responds to any change in light with extreme rapidity and with a remarkable degree of precision.

All photocells have two elements, or electrodes if you wish; an anode which is the positive terminal and a cathode which is the negative terminal. In general, the anode is in the form of a ring placed in the center of the bulb, while the cathode is the thin coating on the inside surface of the glass bulb. The cathode deposit is alkali metal or alkali hydride, all of which we will learn about later.

The cell has what is termed a "window," a clear spot on the glass whereby light may enter and be reflected by the cathode. When a voltage of 135 volts is connected across the terminals of the photoelectric cell, of course the positive terminal to the anode of the cell and the negative terminal of the battery to the cathode of the cell, the device immediately becomes sensitive to light variations which enter the window and electrons are emitted from the cathode.

Light waves, which we understand are nothing more than electromagnetic waves, when striking the cathode cause electrons to be thrown off from the cathode which are immediately attracted by the positive anode.* The rest is simple—a migration of electrons to the anode, around through the circuit and back to the cathode, constituting, in a strict sense, an electric flow. In this case, the electric current was the result of light waves striking the photoelectric cell. Any variations in the intensity of light result in an immediate variation in the electric current in the photoelectric circuit. However, we must realize that we are dealing with infinitely small values of current which can only be measured in microamperes. The action is instantaneous, and for our purpose we can consider that current variations follow light variations without any time difference.

Fig. 1 shows a photoelectric cell of modern construction. The cathode in this particular case happens to be a semi-cylindrical plate sensitized so that electrons will be thrown off when light waves strike it. This plate is often referred to as being photoelectrically sensitive. A simple rod in the geometric center acts as the anode and attracts to itself the electrons which are thrown off the cathode. The glass bulb in one type of photoelectric cell is evacuated so as to make a perfect vacuum. Such photoelectric cells are called vacuum type cells. In other types—which, by the way, are more sensitive—the air is completely pumped out and in its place a rare gas like helium, argon, or neon is used.

A fundamental circuit for the photoelectric cell is shown in Fig. 2, explained in schematic form. A ray of light is shown striking the photoelectric surface, and electrons are thrown off and attracted to the anode. The latter is positively charged by the group of batteries and attracts the electrons into the circuit

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* The free electrons are kept from jumping off the surface of all metals by what is called *surface tension,* the same effect that tends to prevent water from evaporating. If this surface tension is overcome in some way or other, electrons will evaporate from the surface of metal just as water evaporates from the surface when the temperature of the surface is raised sufficiently. We have already learned that, if the surface of a metal is heated sufficiently, electrons will be thrown off. This is the filament emission which we learned about in our study of vacuum tubes. What really takes place is that the heat imparts greater kinetic energy to the electrons, so that the electrons have more energy in them than the force which tends to hold them in place on the surface. In other words, more kinetic energy results in greater motion, and if this motion is sufficient to overcome surface tension, electrons will float away from the metal (filament). In much the same way, when a light wave (very high frequency electromagnetic wave) strikes the cathode of a photocell, the light wave imparts its energy to the electrons, giving them sufficient kinetic energy to break way from the surface of the cathode. The amount of surface tension for different metals varies—those metals with very low surface tension are said to be photoelectrically sensitive.

through the microammeter, the electric battery and through resistance *R*, again to the cathode of the photoelectric cell. The microammeter has been included so that we may have some visual indication of the flow of current. The resistance *R*, although not fundamentally necessary, is an important protective device for the photoelectric cell. Too much voltage or too much light will in some cases destroy the cell, particularly if the photoelectric cell is of the gas type. The resistance *R*, therefore, limits the amount of current that can flow in the circuit and is called the limiting resistance. It should never be below 5,000 ohms.

Battery B will have a voltage ranging from 90 to 200 volts, depending naturally on the type of cell used and the particular sensitivity required. The sensitivity of a photoelectric cell is measured by the current flow per unit of light. The current is measured in microamperes and the light intensity measured in lumens.

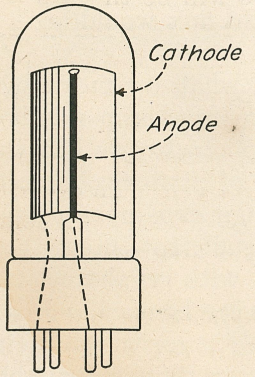


Fig. 1

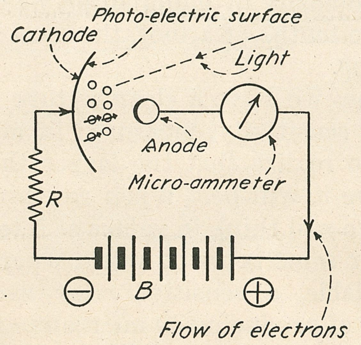


Fig. 2

"Lumens" may be a new word to us. What do we mean by it? The Bureau of Standards has a standard candle, or rather a source of light of one candle power, illuminating a screen 1 foot away. The intensity of illumination on the screen will be one foot-candle. We must look upon light waves as energy, and we must imagine that the candle is radiating energy in all directions. On this very same screen, 1 foot away from the candle, an area of 1 square foot is marked off. The amount of light which passes through this area of 1 square foot each second is called a *lumen* of light.

As we move the screen farther away from the source of light, the intensity of illumination goes down. At a distance of 2 feet, the illumination will be one-fourth; at 3 feet, one-ninth; at 4 feet, one-sixteenth. From which we can see that light intensity varies inversely as the square of the distance.

If the source of light is more than one candle power, let us say seven, regardless of the distance, the illumination will be seven times as much as that furnished by a one candle power source. Therefore, in order to determine the amount of illumination in foot-candles that is at any particular distance, we divide the candle power of the source by the square of the distance, the intensity of the source being in candles and the distance in feet.

In order to determine the amount of light which strikes a surface in one second—in lumens—we multiply the area of the surface in square feet by the intensity of illumination. Thus, if the intensity of illumination was 15 foot-candles, and the area was two-tenths of a foot, the total light flux would be .2 x 15 or 3 lumens.

Now we have a clear picture of what we mean by photoelectric sensitivity, measured in microamperes per lumen. We can also realize that the larger the photoelectric cell the more sensitive it will be. When we think of photoelectric cell sensitivity we will think in values of 5 to 10 microamperes per lumen.

For some types of work, where sufficient intensity of light is available, a sensitive relay used with a photoelectric cell capable of producing 40 microamperes can be used in an arrangement similar to Fig. 3. This is merely a series relay circuit to be used when large changes of light intensity are available. This circuit is directly adaptable for alarm systems and counting machines.

For purposes of light measurements, a circuit as shown in Fig. 2 would be used with a microammeter as the indicating device. The entire circuit arrangement would be calibrated in terms of light units. Such a circuit can be used for photometry of incandescent lamps or other light sources, that is, for the measuring of transmitted or reflected light as is required for the solution of commercial lighting problems.

When we consider that in most cases only between 2 to 5 microamperes can flow in the photoelectric circuit, we immediately realize that intensive amplification is of vital importance. A simple one-stage amplifier, with a relay connected to a photoelectric cell, is shown in Fig. 4. The tube and the circuit are battery operated; the tube is an '01A and the plate feeds directly

into the relay. Notice that the anode of the photoelectric cell and the plate of the vacuum tube—which, by the way, is the anode of the vacuum tube—are in shunt. The grid of the vacuum tube and the cathode of the photoelectric cell are also connected together. A "C" battery to bias the '01A properly is shown in the circuit. The bias voltage is controlled by a 100,000 ohm variable resistor connected across the 9 volt C battery. The 90 to 135 volt B battery serves as the B supply for the photoelectric cell and the vacuum tube. The filament of the vacuum tube is heated by means of its own A battery, controlled by a rheostat. Between the cathode of the photoelectric cell and the B battery connection is connected the limiting resistance of the cell, which in this case is between 1 and 10 megohms.

A milliammeter is placed in series with the relay to indicate the amount of current in milliamperes that is flowing. In the usual commercial installation, this permanent meter is dispensed with.

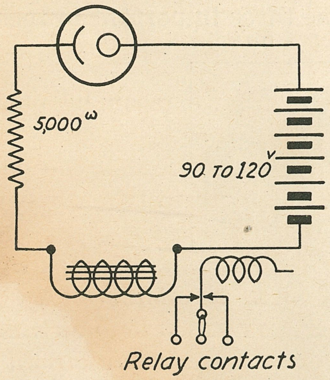


FIG. 3

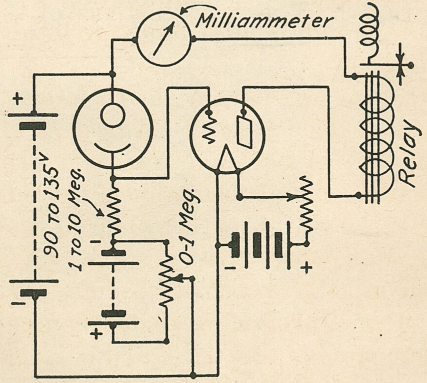


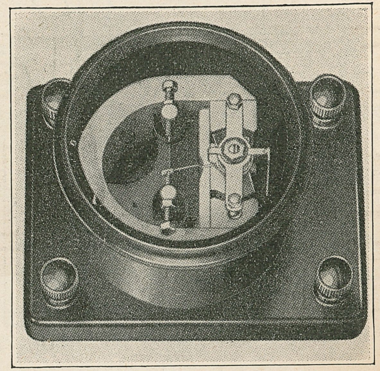
FIG. 4

After being properly set up, this circuit requires only an adjustment of the grid bias by means of the potentiometer across the bias battery. The cell is darkened, that is, light is prevented from entering it and the C bias adjusted so that the meter shows a very small plate current. Now when light strikes the cell, a positive increase of potential appears on the grid and increases the plate current in the vacuum tube.

Both these simple arrangements have wide applications in the commercial field. They may be used for burglar and fire alarms; they may be used to act as optical counters, in timing devices; they may be made to open doors and close them.

During a recent electrical show, a photoelectric cell was ingeniously attached to a water cooler. When the cup was brought near the faucet a ray of light which was directed toward a photoelectric cell was interrupted. Immediately the decrease in light energy reaching the cell caused a proportionate decrease in the current flowing in the circuit. This decrease caused the grid voltage to decrease (see Fig. 4), making it less negative, which resulted in a larger plate current. This current operated a relay which closed another circuit containing a device to open the spigot. Thus the spigot is opened just by placing the hand near it—which a person with no knowledge of photocells might well consider magic. This ingenious hook-up shows very well the commercial possibilities of photoelectric cells with relay action.

Of particular interest to us is the application of the photoelectric cell to *television, talking moving pictures* and *telephotography*. The very existence of these three important branches of human activity depends on the photoelectric cell, and for that reason we shall study this remarkable device in great detail.

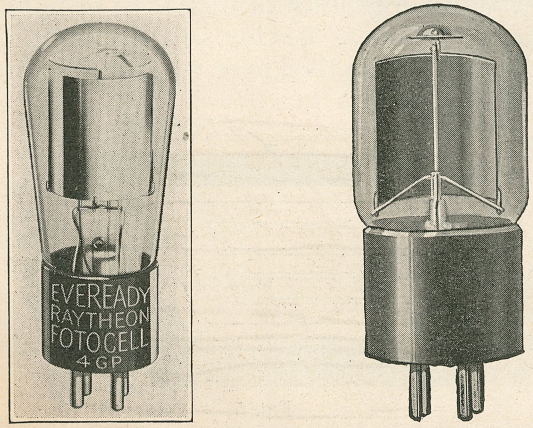

COURTESY JEWELL INSTRUMENT CO.

Typical Commercial Relay

Here we can mention a few more of the many uses of this remarkable device. It is used in lamp photometry, measurement of light absorption, transmission and reflection. It is used as an illumination control; in factories; drafting rooms; also offices where it is desired to maintain uniform lighting throughout. We have already mentioned its adaptation for burglar and fire alarms and, as a matter of fact, it may be extended to any form of alarm whether it be at a bench press in a factory or as an indication that someone has entered your home or office through the front door. One ingenious inventor made use of the photoelectric cell in conjunction with his outer reception office in this manner; when an individual entered the room, a light was interrupted which immediately started a phonograph and, in a very few words, welcomed the visitor, asked him to be seated, and said that he would be seen shortly. Almost a magical performance.

In a few cigar factories, cigars are being graded according to color by means of the photoelectric cell. In fact, where products vary in color this particular color sensitive device may be used as an assorter. In factories where rigid inspection is demanded of each mechanical part, the photoelectric cell has been used to detect flaws in raw and finished products.

Pyrometry—the sensitive measurement of temperatures—is made complete and exact to a degree never before possible by means of our electric eye. Control and measurement of the amount of smoke from boiler stacks has also been added to its list of achievements. Accurate control of temperature, speed control of machines and frequency control of devices, too, can be claimed for it. As time goes on, there will be many more uses found for the modern photoelectric cell.



COURTESY G-M LABORATORIES

Typical Commercial Photoelectric Cells

PHOTOELECTRICITY

Credit for the discovery of the photoelectric process, which we shall shortly describe, goes to men who are well known in the science and development of electricity—men like Hertz, J. J. Thomson, Hallwachs, Einstein. Let us pay tribute to their efforts and pass on to modern concepts of this remarkable invention with which they did pioneering work.

Let us begin with a study of the very first light sensitive cell, the selenium cell. Although not used at the present time in sound projection or television, it is the forerunner of the photocell, and a careful study of it will provide us with a background after which we will be ready to consider the present-day photoelectric apparatus.

As far back as 1873 it was known that the metal selenium, when heated to 200° Centigrade, became a rather poor conductor of electricity. Quite by accident it was discovered that the conductivity of selenium increased with its exposure to light. Engineers, who were interested in picture transmission, immediately saw the possibilities of such a substance. A resistance unit made of this material, when exposed to variations of light, would produce variations in current flowing in the circuit. Then these variations could be transmitted over wires to a recording device.

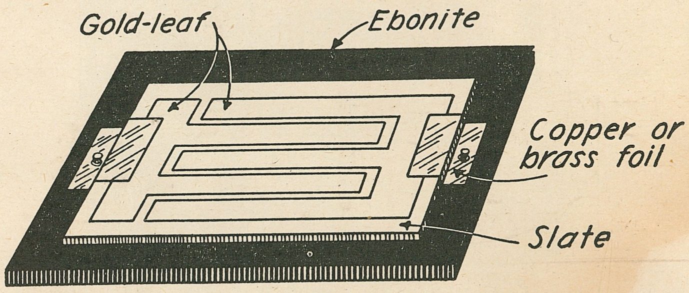


Fig. 5

Light striking the cell would decrease its resistance. When the light was removed, the resistance of selenium would be as it was originally. Thus, intermittent flashes of light on the cell would result in surges of current over transmitting wires.

A practical selenium cell is shown in Fig. 5. It consists of two electrodes in the form of a series of "T's" which are interlocked but without any connection between the two electrodes. These are made of thin gold and laid on glass or slate. Selenium is painted on and bridges the spaces between the two electrodes. After painting, the selenium is heated up very nearly to its boiling point—690° Centigrade—which changes it to a gray, crystalline substance. This finished element is sealed in a vacuum with two leads from the two electrodes. If a voltage is applied to the two terminals, a current will flow, even though the cell is located in a dark room. If a beam of light strikes the cell, we will have the effect graphically shown in Fig. 6. Light striking the selenium cell decreases its resistance and the current in the circuit immediately rises, quickly at first, and then reaches a point of saturation. It takes about four to five seconds for the current to reach maximum, and when the light is turned off it takes even more time for the current to go back to its original value.

A cell of this sort would be effective, obviously, for devices requiring only intermittent relay action where instantaneous response is not of prime importance. In our modern age, which requires rapidity of performance, four seconds is a long time. In television and sound picture work the selenium "cell" is entirely out of the question, as responses must be had in thousandths of a second. The photoelectric cell, with its remarkable rapidity and sensitivity, has entirely replaced this type of light sensitive cell.

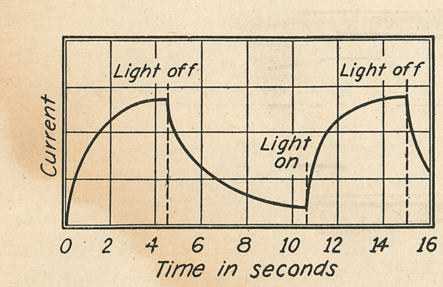


Fig. 6

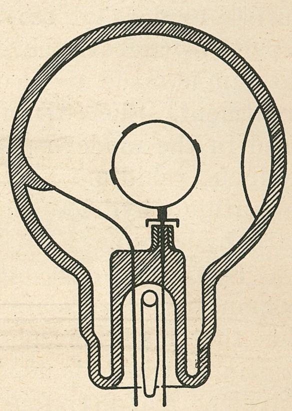


Fig. 7

The term "photoelectric phenomenon" has been defined as the electrical effect which is produced by reaction of light or similar radiation of short electromagnetic waves when striking a metal, particularly the effect of the emanation of electrons when that metal has been subjected to light. Although most metals show this particular effect to a certain degree, the emission from certain definite metals is particularly large. The electrons which have been liberated by this light action are referred to as "photo-electrons."

Metals such as sodium, potassium, caesium, commonly call *alkaline* metals, show this property to a remarkable extent. These metals are chemically very active and combine readily with other substances.

The use of the alkaline metals alone results in a cell which is not particularly photoelectrically sensitive. Furthermore, the metals themselves will respond only to a marked degree when ultra-violet rays are used. In commercial fields we must remember that most light is within or below the ultra-violet wavelength. Therefore such cells are not readily adapted to commercial use.

It is well to note here that there are other metals called *alkaline earth metals* which have been used in the construction of photoelectric cells. They include calcium, strontium and barium. We find calcium, for example, in calcium carbonate—pure marble, chalk and limestone; strontium, we find in the red flares used in fire works; barium gives us the green light so commonly seen in fire works. A remarkable discovery was made when scientists found that most all the alkaline metals had their light sensitivity increased by treatment with the gas "hydrogen." Potassium is made about one hundred times as sensitive by such a treatment. Such alkaline metal hydrides are quite universally used in the modern photoelectric cell. Thus we have caesium hydride, rubidium hydride, potassium hydride, sodium hydride and lithium hydride, all metals which have been specially treated with hydrogen.

By far the most important discovery was that these hydrides responded to the colors which were visible to the eye, and it was this that made the photoelectric cell commercially practicable. Caesium hydride is most sensitive when used with yellow light, a wavelength of fifty-four hundred *Angstrom** units, while sodium hydride responds best to violet light, a wavelength of forty-two hundred Angstrom units. Potassium hydride shows maximum sensitivity when under the influence of blue light, a wavelength of forty-six hundred Angstrom units. Thus a photoelectric cell is color-sensitive and readily adapts itself to the selection of different colors, making possible color television and color sorting.

A cell made with a cathode of potassium hydride is extremely sensitive over the entire range of wavelengths which are included in the visible spectrum. Its value in commercial adaptations for everyday use is obvious.

Many processes have been evolved to deposit a single layer of metallic coating on the inside of the photoelectric bulb in order to create the essential cathode electrode. The method of doing this is strictly a chemical process which we need not go into here.

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* See page 12 for explanation.

Man's knowledge of photoelectric chemistry is by no means complete, and chemists in our largest research laboratories are working daily to increase the sensitivity of the photoelectric cell. Do not infer from our previous discussion that only hydrides are used for the cathodes of photoelectric cells. A recent photoelectric cell developed by the General Electric Company, and later improved upon by the Westinghouse organization, uses what is known as a caesium oxide silver coating, resulting in a cell having a light sensitivity of 25 microamperes per lumen.

Many of the large photoelectric cells have spherical bulbs. The inside surface is coated with one of the many chemical photo-sensitive materials. These materials are deposited around the inner surface and led to one of the leads of the photoelectric cell. The anode in this particular construction is a circular loop in the center of the bulb and usually with the circumference at right angles to the direction of the light. An internal sketch of such a photoelectric cell is shown in Fig. 7, whereas a commercial photoelectric cell of this type is shown in Fig. 8.

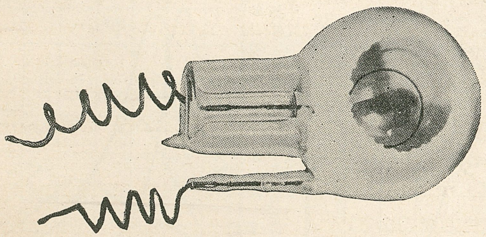


Fig. 8

When studying the photoelectric cell, we must remember that we are dealing strictly with electromagnetic waves, related to Radio waves, the only difference being in wavelength. In our study of Radio transmission and reception, we learned very early that there was a difference between a Radio wave of 60,000 meters, 1,000 meters, 500 meters, 200 meters, 150 meters, or 10 meters. We acknowledged that all were Radio waves, but, due to their difference in length, their behavior was radically different. If we stretch our imaginations, and conceive of electromagnetic waves of extremely small length, we can immediately realize that we are encroaching on a new field, outside the realm of Radio, but still depending on electromagnetic energy.

Electromagnetic waves whose lengths are between 4×10^{-5} centimeters and 8×10^{-6} centimeters are visible. We recognize them as light and not as electromagnetic waves, and we recognize them as red, orange, green, blue and violet. Where there is a mixture of electromagnetic waves, we probably perceive them as brown, purple, cerise, gray and other modified colors.

In the measurement of light waves, the centimeter is a very large unit. It is customary to use the Angstrom, which is equivalent to one hundred-millionths of a centimeter. The abbreviation for Angstrom is A. Thus the spectrum of visible light lies between 4,000 A and 8,000 A.

When studying the relation of the human eye to visible light, it is customary to consider the relative visibility of various wavelengths. Fig. 9 shows the variation of wavelengths measured in Angstrom units with the relative response of the eye. Note that the eye responds best to the wavelength of 5,500 A, tapering off for wavelengths above and below 5,500 A. The relative intensity of visibility is comparatively small at wavelengths 4,000 and 7,000 A. Wavelengths of 4,000 A are ultra-violet rays; wavelengths above 7,000 are infra-red rays. Between these two extremes we have the visible colors. At 7,000 Angstroms we have red; between this and 6,000 we have orange and yellow; between 6,000 and 5,000 yellow and green; and between 5,000 and 4,000 we have blue and violet. Consequently, our eyes respond most easily to yellow light, according to Fig. 9.

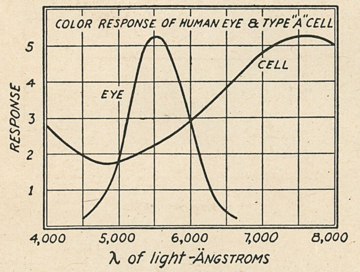


FIG. 9

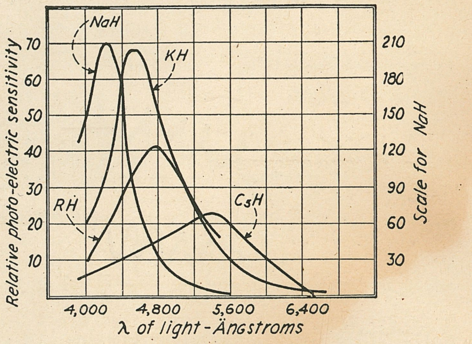


FIG. 10

Compare the visibility of a typical gas-filled photoelectric cell with the human eye. This is shown on the same graph (Fig. 9), and indicates fair response to electromagnetic waves over the entire band between 4,000 and 8,000 Angstroms. From this we can see that the photoelectric cell is far more efficient than the human eye.

Now we can understand more thoroughly the relative response of photoelectric cells made with rare earth hydrides. Typical response curves of various cells, using sodium hydride (NaH), potassium hydride (KH), caesium hydride ($\mathrm{C_sH}$) and rubidium hydride (RH), are shown in Fig. 10. These curves are for photoelectric cells having their elements in a vacuum. Most electrical light sources emit a blue-white light. Under these circumstances, we can see why potassium hydride is the base of the most common cathode in photoelectric cells, as it is very sensitive to blue wavelengths or 4,600 Angstrom units. But, with the use of different cathodes, it is possible to build photoelectric cells sensitive to lights of various colors. Of course, if we calibrate a photoelectric cell in terms of Angstrom units, it is possible for the cell to distinguish various colors and this principle is used quite extensively in commercial fields for color discrimination.

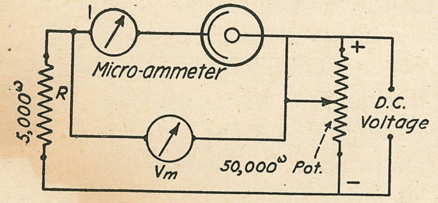


FIG. 11

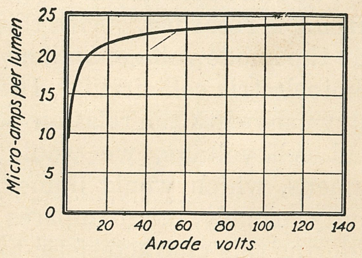


FIG. 12

ELECTRICAL CHARACTERISTICS OF PHOTOCELLS

The primary purpose of a photocell is to take a ray of light and transform it by means of the photoelectric phenomenon into a current disturbance. We have already learned that the stronger the light the stronger the current flow. We shall also learn that the greater the voltage placed in series with the photoelectric cell, the larger will be the current flow, that is, if a light is directed to a photoelectric cell, an increase in voltage will result in an increase in photoelectric current up to a certain point. Just as in vacuum tubes, motors, generators, or any electrical device, from a practical point of view we are intensely interested in operating curves, so, too, with photocells. Let us proceed to obtain and analyze the necessary characteristic curves.

Fig. 11 shows the fundamental circuit for determining the two characteristic curves so essential in photoelectric practice. Note that the photoelectric cell is connected in series with a microammeter and bridging the two devices is a voltmeter of extremely high resistance, in order to measure the applied cell voltage. In series with this is a limiting resistance R of 5,000 ohms and a variable applied D.C. voltage which is controlled by means of a 50,000 ohm potentiometer.

We shall first proceed to study the characteristics of a *vacuum* type photoelectric cell which we understand has a cathode of any of the various possible constructions and an anode, all placed within a vacuum bulb from which every conceivable particle of air has been pumped.

A constant ray of light is focused on the photoelectric cell which is, let us say, about 1/10 of a lumen. The voltage between the anode and the cathode is varied by means of the potentiometer, and at various cell voltages the current in the photoelectric circuit is recorded. With this information we can plot as abscissas the anode voltage and, as ordinates, the microamperes in the photoelectric cell circuit. If we were particularly interested in a curve showing the relation between photoelectric cell sensitivity and cell voltage, we would divide the microamperes by the lumens, which would immediately give us the total cell sensitivity, namely, microamperes per lumen. It is customary in considering this characteristic to consider the various photocell sensitivities as the cell voltage is varied. Such a curve is shown in Fig. 12. You will notice that as the anode voltage is raised from zero to 10 volts, the sensitivity of the cell rises very rapidly and at a voltage between 20 and 40 reaches an almost constant value. We say that here cell current reaches a saturation value. Clearly there would be no advantage in using an anode voltage over 40 volts in this particular case, as nothing would be gained in photoelectric cell sensitivity.

We might then proceed to take other curves, using one-half a lumen of exciting light, or two hundredths of a lumen, and accordingly obtain different curves, one above and one below this particular curve, depending on whether we used a stronger or weaker light than one-tenth of a lumen.

Rather than make a series of curves like the one in Fig. 12, we might proceed by applying a constant anode voltage of 40 volts and vary the number of lumens that were focused on the photoelectric cell. Assume we are able, by laboratory methods, to determine the intensity of light flux. As we vary the light flux from a part of a lumen to 2 or 3, the current in the photoelectric cell circuit is recorded, and with this information a plot is made between light flux in lumens and microamperes per lumen (microamperes in the photoelectric cell).

Such a curve is shown in Fig. 13, and this curve brings out some very important facts. It is the basic curve which determines the photoelectric cell's adaptation to sound pictures. You will learn later, when studying sound pictures, if you are interested in this subject, that sound can be turned into varying light. Varying light may be recorded in the form of various shades of light on a celluloid strip. This forms the record. Then, when an exciter lamp is connected optically with the photoelectric cell and the record placed between the two, a current will flow in the photoelectric circuit in accordance with the frequency variations of the original sounds. Clearly, if the "light flux against microamperes" characteristic curve is a straight line, we would expect to obtain perfect conversion from light to sound, that is, perfect reproduction. As you will see in Fig. 13, this characteristic is strictly a straight line and one of the important problems of sound pictures is solved, the problem of exact reproduction.

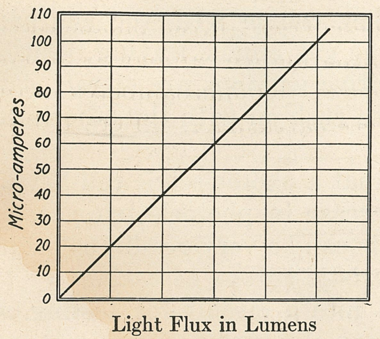


FIG. 13

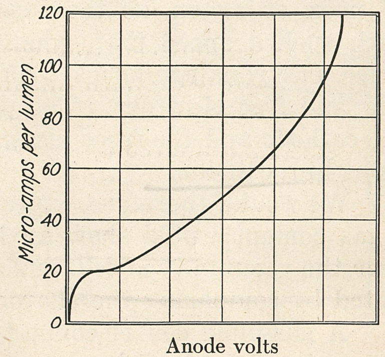


FIG. 14

GAS FILLED PHOTOELECTRIC CELLS

In a vacuum type photoelectric cell, the striking of the electromagnetic waves against the cathode liberates a definite quantity of photoelectrons. Consequently, as the voltage is increased between the cathode and the anode, the latter being positive, more and more of these liberated photoelectrons are attracted to it until finally at some voltage the plate cannot attract any more. This is the saturation point which was previously mentioned.

The presence of gas, however, in a photoelectric cell has an effect on the number of electrons which are attracted to the anode. We are, therefore, very much interested in the electrical behavior of the gas-filled photoelectric cell. For our purpose let us assume that all the air has been drawn out of the bulb, and gas, such as neon or argon, has been forced into the glass bulb. We have already studied the subject of ionization as applied to vacuum tubes, so that this subject is by no means strange to us. When the gas-filled photoelectric cell has a flux of light directed to the cathode, electrons are emitted from the sensitized surface. These electrons rush at a tremendous speed toward the anode and in doing so strike against the gas particles of neon or argon, as the case may be. The electrons move with such a speed that, when they collide with the gas particles, electrons are knocked off the gas atoms, leaving positive ions and free electrons. The positive gas ions are attracted to the cathode and the freed electrons rush on with the other electrons to the anode.

We would, therefore, expect that a photoelectric cell having a gas content would show an increase in photoelectric current over the vacuum type cell, and this can be very readily substantiated by comparing the characteristic curves of each.

A gas-filled cell is connected into a circuit for testing, as shown in Fig. 11, and a set of data obtained to draw our customary "anode volts vs. microamperes per lumen" curve. Plotting this data, we get a curve as shown in Fig. 14, and upon analysis we find that with a given number of lumens applied to the photoelectric cell, which, of course, is kept constant, as we increase the anode voltage from 0 to 10 volts, the cell behaves much like a vacuum type. As we further increase the cell voltage, we reach a saturation point which is practically constant until an anode voltage of 20 is applied. From this point any increase in anode voltage shows a rapid increase in the photoelectric cell sensitively until about 105 volts. A further increase in the anode voltage clearly would cause a tremendous increase in the photoelectric cell current.

At this point, the student should be warned of a very important fact about a photoelectric cell having a gas content. If the anode voltage in this particular case was kept for any length of time at more than 105 volts, the cell would destroy itself.

This subject being so important, we are naturally interested in determining where the steep portion of the curve would be if we used various intensities of light flux. Fig. 15 shows a series of "voltage vs. photoelectric sensitivity" curves, plotted for various light fluxes, namely, 0.6, 1, and 1.4 lumens. As you will observe, on the 0.6 lumen curve the steep portion appears at 140 volts. This drops to 133 and 125 for the 1 and 1.4 lumens, respectively. Therefore, for a given light flux, the cell voltage should not be exceeded over a definite set value, and to be perfectly safe it must be fairly well below this self-destroying point.

There are two methods available for determining this limit of voltage. One, of course, is by means of an anode voltage vs. photoelectric current characteristic curve taken under actual operating conditions, using the regular light source at maximum intensity and varying the applied anode voltage. The cell voltage is then fixed at a point below the sharp increase in photoelectric current. In the curves shown in Fig. 15, these would be, respectively, 115 volts for 1.4 lumens, 125 volts for 1 lumen, and 130 volts for 0.6 lumen.

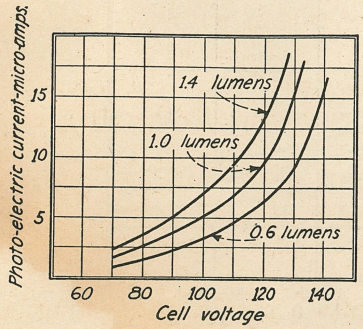


Fig. 15

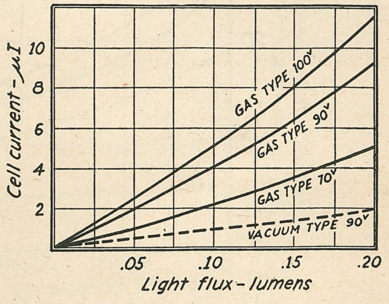


Fig. 16

In the second method, the maximum light flux from the regular source is allowed to enter the cell and the voltage raised until a visible glow is produced. As it is quite difficult to observe the glow when the cell is illuminated, this effect can be detected by alternately covering and uncovering the cell window while the cell voltage is being gradually raised. Of course, we do not want to raise the voltage high enough so that the cell will glow continuously. We are able to detect sustained ionization by means of a series-microammeter. The current flow should return to zero each time the light is cut off, and will, provided there is no sustained ionization. When the cell voltage has been raised to a point where sustained ionization takes place, the meter will show a current passing after the cell has been darkened. When this point is reached, the voltage should be immediately reduced until the glowing stops. The maximum safe operating voltage is slightly below this value. Glowing for any length of time is detrimental to the cell, and it should not be allowed to glow unnecessarily. Above all, under no conditions should the cell be tested without an extra series resistance or other current limiting device.

Fig. 16 shows the other characteristic curve, light flux against cell current, and you will observe the variation is practically a straight line. This curve shows a comparison between the vacuum type and the gas type cell, and it should be clear to you that the vacuum type is not as sensitive as the gas photoelectric type. As the voltage is increased, considering the gas type cell, the current increases, but we must bear in mind that too much voltage is unsafe. As a matter of fact, you will notice that at the higher voltages there is a tendency for the current to increase rapidly at large light fluxes, and this is shown in the curve by a gradual increase in the slope of the line. The vacuum type cell shows practically a straight line characteristic to all light fluxes.

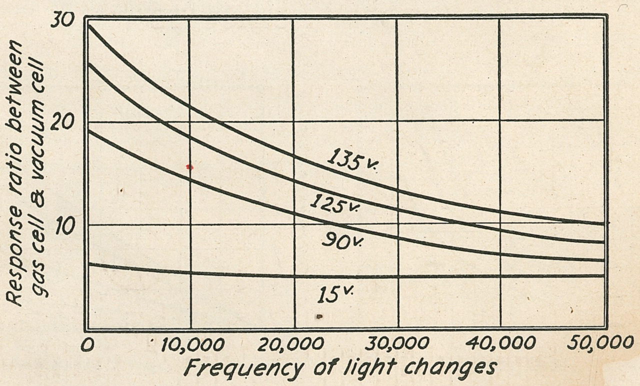


Fig. 17

The electrical characteristics of photoelectric cells just studied are static characteristics and do not take into account light sources which vary rapidly. The vacuum type photocell responds uniformly to light, regardless of variations. How frequently these light changes occur has but little effect on the characteristics. However, in the case of the gas-filled cell we must consider the dynamic response. Fig. 17 shows this characteristic clearly with a fixed anode voltage and at the same time a fixed light flux, the frequency of the light changes (flickers) being varied between zero and 50,000 cycles per second.

With low cell voltage, the response of the cell is practically constant. When a substantial cell voltage is applied, response is quite good at low variations in light and response decreases rapidly as the number of variations is increased to 50,000 times per second. This particular characteristic is very important in television work where light variations will be even greater than 50,000 cycles. For present television transmission, the dynamic characteristic should be as flat as possible.

PHOTOCELL CIRCUITS

We must learn from the outset how to connect a photoelectric cell with a vacuum tube amplifier. The two are inseparable in practice. Fig. 18 shows the basic fundamental circuit for photocells with a vacuum tube amplifier. The resistance R is placed between the anode and the voltage feeding the photoelectric cell. Fluctuation of light in the cell causes a current to vary in the photoelectric circuit and, consequently, a varied IR drop appears across the resistance. This voltage now acts as the input voltage to the vacuum tube, which is used purely as a vacuum tube amplifier. The varying grid voltage results in a varying plate current in the vacuum tube output circuit. The larger the value of the resistance R, the greater will be the grid voltage variation applied to the vacuum tube, and by making R exceptionally large the vacuum tube can be made to have a large over-all amplification together with the photocell circuit.

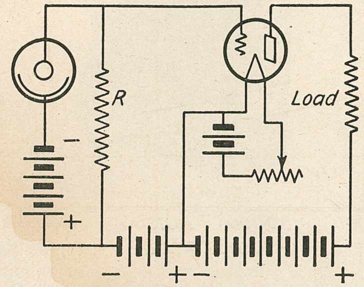


Fig. 18

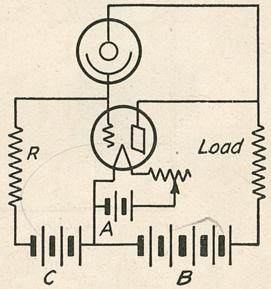
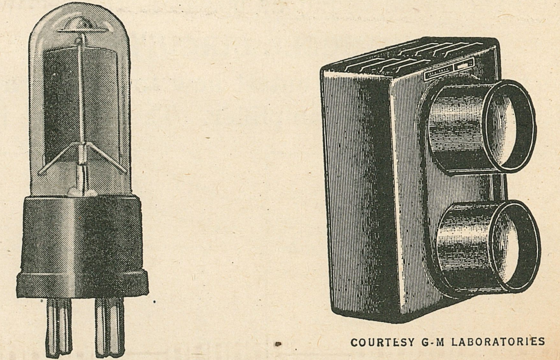


Fig. 19

In commercial circuits a single source of e.m.f. is used for both the cell and the plate of the vacuum tube. Fig. 19 shows a combined photocell-vacuum tube circuit using a common B voltage. Note that the cathode of the photocell and the grid of the vacuum tube are connected together, whereas the anode of the cell and the plate of the vacuum tube are connected together. The photoelectric cell current flows from the anode to the cathode, through the resistance *R*, through the C and B batteries, into the plate resistor, back to the anode again. The voltage across *R* acts as the varying voltage for the vacuum tube amplifier which reappears again, amplified, in the plate circuit.

A combination of a photocell and vacuum tube amplifier has been made as a single unit and satisfactory results have been obtained.



COURTESY G-M LABORATORIES

Commercial photoelectric device with light source self contained. Light is directed out of one opening and is reflected by an external mirror into the other to operate the photocell. When the light is interrupted the photoelectric current is changed. This change is made to operate a relay. The cell used is shown at the left.

Quite often it is necessary to amplify the small photoelectric current to an appreciable degree. In fact, the photoelectric current, which usually amounts to only a few microamperes, has to be amplified to several milliamperes if we are to obtain clear pictures in the case of television and good volume in the case of sound amplification. In television work, ten stages of amplification are by no means uncommon. The problem of designing an adequate amplifier is a task. Compare three to ten stages of audio amplification for photoelectric work with two to three stages only as used in ordinary Radio receivers.

Fig. 20 illustrates a three-stage photocell amplifier. It is designed for direct current operation and each tube has its own A-B-C supply. This applies the principle of direct coupling, necessary when we deal with currents which do not have periodic variations—that is, this type of an amplifier will amplify single impulses as well as periodically varying signals. Separate battery supplies make for instability of the amplifier because of the possibilities of variations in the voltages of individual batteries.

When dealing with commercial applications of the photoelectric cell using amplifiers we are always concerned with efficient means of supply and, of course, for commercial purposes, A.C. is universally used. Fig. 21 shows the adaptation of A.C. to photocell operation in a three-stage direct coupled amplifier. Notice that the tubes are fed by raw A.C. directly from a step-down transformer. The B supply is obtained by means of a regular rectifying system, using high voltage rectification with a bleeder resistance connected across the rectifier output. Various voltages are obtainable from the drop wire feeding the plates of the various tubes in order. When this system is used for relay purposes, the small trace of 60 or 120 cycle ripple which will get into the amplifier is not serious. The grids of the first and third tubes are biased to reduce their respective plate current to a minimum, while the grid of the second tube is so biased as to allow a maximum plate current. Thus, when the first grid becomes positive, the plate current through R_1 increases, so the second tube becomes more negative and the third grid in turn becomes more positive. There is a serious possibility of regeneration in this type of circuit which we must guard against. Otherwise sustained oscillations will result. This instability characterizes all multi-stage amplifiers of pulsating D.C. having large over-all amplification.

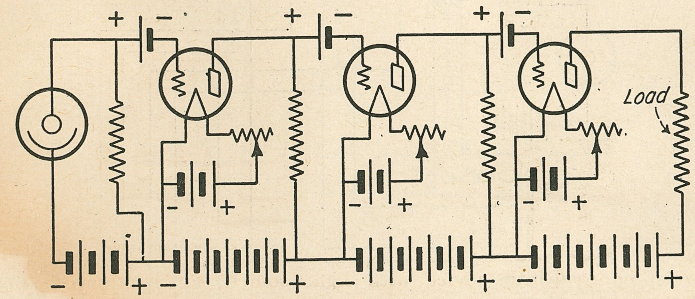


Fig. 20

As we have pointed out before, the circuits just described were intended primarily for light sources which do not vary through complete cycles (off-on) but, rather, for sources which produce pulses of steady light. In television and sound pictures we deal with light sources that vary between very low frequencies to as high as 50,000 cycles per second. In talking pictures the upper limit of frequency variation is normally 10,000 cycles per second. When this is the case, we are able to couple successive vacuum tube stages by regular audio coupling methods, namely, resistance, impedance, transformer. We must bear in mind, however, that only resistance coupling is feasible in television amplifiers where the frequency will be as high as 50,000 cycles.

When dealing with varying light intensities, we usually speak of them as A.C. signals, and our choice of vacuum tube amplifiers depends entirely on the fidelity, gain and frequency range desired of the photoelectric system. Fig. 22 shows a typical three-stage resistance coupled amplifier, particularly adaptable to television amplification. The number of stages depends entirely upon the gain desired. We must bear in mind that the gain per stage for a resistance coupled system is ordinarily about .75 times the "mu" of the tube (a loss by virtue of this type of coupling), and in order to compensate for this, the UX-240 tube having a large "mu" is universally used. The screen grid tube has also been successfully used with resistance coupled amplifiers, particularly because of its large gain per stage. When using resistance coupling, the size of the coupling condenser determines the low frequency range of the system. The use of the screen grid has increased the frequency range to 80,00 cycles per second.

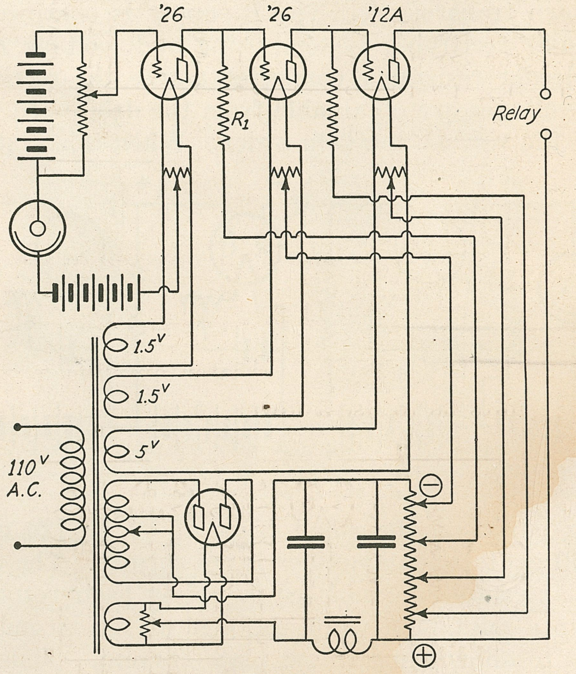


Fig. 21

For audio frequency ranges from 25 to 10,000 cycles, very uniform amplification is obtained with transformer coupling. The circuit reproduced in Fig. 23 is similar to any of the ordinary audio amplifiers used in Radio and sound picture amplification, with the exception of the photocell input. The use of transformer coupling allows a greater amplification per stage and also permits us to use a lower voltage on the vacuum tube plates. Hi-Mu tubes are not used. In general practice amplifier design is identical with audio frequency amplifier design.

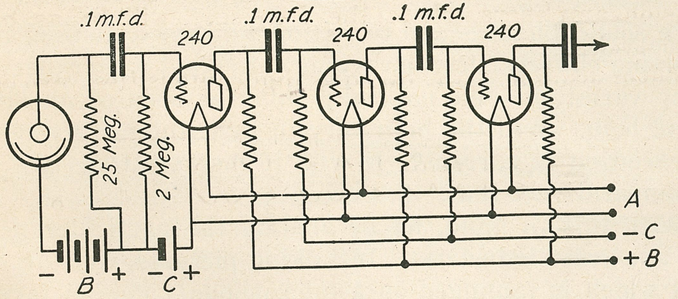


Fig. 22

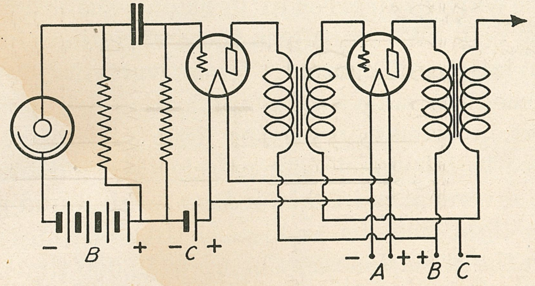


Fig. 23

In some circuits shown, the output is shown as a resistance in the plate of the last tube. If the photocell amplifier system is used for relay work, this resistance represents the relay. When used for television work, it represents the input to the modulating system of the transmitter, and when used for sound picture work it represents the loudspeaker load, assuming, of course, that the last tube is a power amplifier and the entire diagram represents the amplifying system from the photocell through the power amplifier. In general practice, however, only one or two stages of amplification are close to the photoelectric cell. These are referred to as head amplifiers which feed into the power amplifier.

GLOW LAMPS

In sound pictures and television we have a distinct need of converting electric current varying through a wide range of frequency variation. We naturally think at once of an ordinary electric bulb. Will the bulb vary in light intensity when there is a variation in current? It will, if the variations per second are comparatively few.

With this in mind, let us analyze the particular needs of these two great industries. In talking pictures, we start with a sound which is impinged on a microphone. This is forwarded through several stages of amplification and then either recorded on a phonograph disc—or a record, as we usually call it—or is changed into varying light shades and the record made on a celluloid strip. If a light can be made to vary in intensity in exact accordance with sound variations, a photograph in terms of light and shade can be made on a motion picture film.

In television work we start with a picture or scene and we translate the various degrees of light and shade by means of a photoelectric cell. We transform these variations in light intensity into variations of current. These variations are amplified through successive stages of amplification without distortion, and again reconverted into varying light intensities. Of course, there is more to television than merely this, but essentially the process of conversion is in this order. With sound pictures, the variation in light may be as high as 10,000 times per second. In television the variations may be up to 80,000 times per second.

An ordinary 25 watt bulb draws approximately a quarter of an ampere, while a 100 watt bulb draws about 1 ampere. This large amount of power, absorbed by a bulb in converting electricity into heat and then into light, gives us an idea of the amount of heat emitted by the filament. The result is that when a bulb is lighted and the current turned off, the heat and light persist for a definite length of time, and in general it is found that it will continue for about a tenth of a second. In other words, it will follow with some degree of exactness a frequency

of 10 cycles per second. Clearly a device that responds to current changes so slowly is not applicable either to sound pictures or television.

The advent of the glow lamp has solved this vital problem. The ordinary glow lamp will respond to changes in light intensity as often as 100,000 times a second. Hence, it is universally used at the present time in television. This glow lamp uses neon and was originally developed by D. MacFarland Moore. In sound picture work a different type of glow lamp is used, developed originally by the Case Research Laboratories for use in this field.

Essentially, a glow lamp consists of two electrodes in a sealed glass tube from which all the air has been first pumped out, and an inert gas, such as helium, neon, or mercury vapor, pumped in. Glow lamps using neon and mercury vapor are common at the present time. They are used extensively in advertising signs because of their peculiar brilliancy and also because they can be seen for long distances even in the daytime. Neon tubes emit a red light, whereas mercury vapor emits a blue light. The special glow lamp used in sound pictures, known as the Aeolight, using helium, emits a bluish-white light and is particularly useful in photographic work.

We are naturally interested in the electrical effect of the gas between the two electrodes. When a D.C. voltage is connected between them, one is made positive and one negative. Within the glow lamp is the gas, and in this particular volume of gas between the two electrodes there are always at least a few free electrons. Neither of the electrodes is photoelectrically sensitive and, therefore, light can not cause electrons to be set free from the cathode. However, if the voltage is great enough and the electrons have a rather free path, they are attracted immediately to the positively charged electrode. As they are attracted, they gain speed, and in their journey toward the anode they knock up against gas molecules—let us say in this case the gas is neon. At that instant the electrons from the filament lose their energy, but the gas molecule is broken up into an electron and a positively charged gas ion. There are now two free electrons in place of the original one, and these two are attracted by the positive electrode and rush toward it. In the meantime, they strike up against more gas molecules, increasing the number of free electrons rushing toward the anode.

At the same time the positively charged ions rush toward the negatively charged electrode and, striking it with tremendous force, liberate more electrons which speed on their way to the anode. Not all the electrons which are liberated by either process go to the anode. Some of them re-combine with the positively charged ions to make a complete neutral molecule of neon. For every particular current flow through the tube there is a point of equilibrium. If the applied voltage varies, there will naturally be a varying current in the glow lamp, with the result that there will be an increase and decrease in the electron flow. This turmoil of electrons causes electromagnetic waves which we recognize as light to be radiated. If the gas is neon, it will be a reddish light which glows visibly even in the daytime. With varying current the light increases and decreases rapidly.

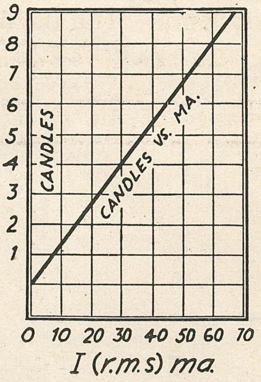


Fig. 24

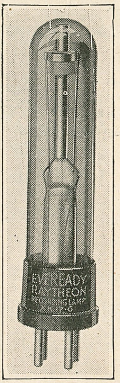


Fig. 25

This particular phenomenon of ionization applies to all gases, even hydrogen, nitrogen and oxygen, but these do not produce any visible light. Glow lamps, containing helium, neon, argon or mercury vapor, are generally employed. For electrodes of a given size spaced a certain distance apart, the required voltage to produce ionization will depend upon the gas used and how much of it is in the glass tube.

If we were to measure the light emitted by a glow lamp for various current flows through the glow lamp and plot our information, we would get a curve similar to Fig. 24. You will notice the curve is a straight line and, if the current represents a signal, the light will vary according to the original signal. This particular action is very important in the recording of sound pictures. Fig. 25 shows a Case "Aeo-light," of which the gas content is mostly helium. It is a tubular shaped lamp, about 6 inches long and 1 inch in diameter, inside of which there is a plate which is the positive electrode. The negative electrode or filament is covered with oxides of barium strontium, and the gas content of the lamp is about as follows: ½ per cent nitrogen; 3 per cent neon; and 95½ per cent helium.

When about 350 volts D.C. is applied across the Aeo-light, in series with 12,000 ohms, a bluish-white glow is established within the tube. The D.C. voltage is adjusted until about 10 milliamperes flow through the glow lamp. The purpose of the 12,000 ohm resistance is to stabilize the Aeo-light circuit because in a gaseous tube of this type, after the gap between the electrodes has been ionized, the impedance of the circuit is liable to become lower and lower until it is practically a short circuit. It is used as a series limiting resistance, connected across the output of the amplifier so that variation of voltage across the system causes light emitted by the glow lamp to increase and decrease in intensity. An Aeo-light circuit is shown in Fig. 26.

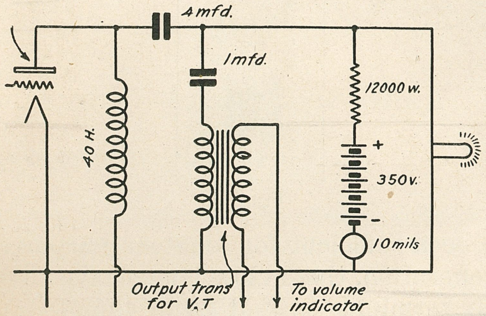


Fig. 26

The Raytheon Kino Lamp manufactured by the Eveready Raytheon Corporation is a typical glow lamp used by amateurs in the field of television today. See Fig. 27, which shows a typical Kino Lamp. This type of lamp does not provide a concentrated glow which can be focused as do some glow lamps, but the glow is distributed over a large surface. The reason for this is that the negative glow, as it is called, should cover an area equal to that of the picture which it is desired to receive.

This area is obtained by having a plate surface, usually rectangular, faced by mica on the cathode side and having on its periphery, spaced about 1/8 of an inch away from it, a rectangular loop of wire which acts as the cathode. When the gas is ionized, the tendency is for the current to flow from the cathode to the anode by the shortest route, but in this case current is prevented from flowing from the cathode to the nearest side of the anode by the mica facing. Therefore, current must flow through the ionized gases from the cathode to the front plate—the far plate—of the anode, and the glow appears on the front face of the plate which is the useful surface of the glow lamp.

Up to the present time, pictures about the size of a kodak snapshot have been sufficient for amateur purposes.

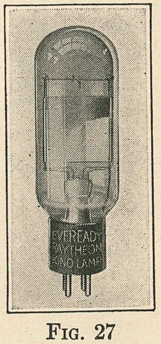


FIG. 27

In actual operation, these glow lamps have sufficient voltage applied to their terminals so that 20 to 40 milliamperes of current will flow through the tube. This voltage is really an exciting voltage. When a glow lamp is connected to the output of a television receiver, the light from it will increase and decrease in intensity, to conform with the original scanning at the transmitting studio.

TEST QUESTIONS

Number your answers 25FR1 and add your *Student Number.*

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. What happens when a light wave strikes a photoelectric cathode?
2. Name the two types of photoelectric cells.
3. Which of these is the more sensitive?
4. What two precautions must be observed in operating a gas filled photocell?
5. Explain "ionization" in a photoelectric cell, briefly.
6. Draw a fundamental photocell circuit with one stage of amplification.
7. Explain the electrical action from the time the light strikes the cell to the time it reaches the amplifying tube plate.
8. What gas when used in a glow lamp will produce a bluish light?
9. Why is mica used in the Raytheon Kino Lamp?
10. In what way is the modern photoelectric cell much superior to the selenium cell?